LCA Case Studies

Zinc Casting and Recycling

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Abstract

Aim, Scope and Background. Metal die casting is a highly energy-intensive industry. In addition to that, the production of primary zinc by smelting consumes huge amounts of energy as well as generates many types of pollution. This paper uses LCA to investigate the environmental performance of a zinc cast product. The areas of environmental concern are focused on the direct and indirect air emissions that arise from the Zinc Smelting, Casting and Recycling, as well as transportation.

Main Features. The LCA case study employs a cradle-to-gate approach, which starts with the purchasing of primary zinc from abroad, casting, inspection, and ends when the scrap metal is sent back for recycling by truck. Based on a 'generic' zinc casting product, the objective of the LCA was to compare the air emissions from the material cycle due to: i) the increased content of recycled metal in the final cast product; and ii) the choice of selecting between two Remelters (A and B), the first located near the company and the other in a neighbouring country, to send zinc scrap for recycling. The LCA SimaPro software (version 5.0) Eco-indicator '99 method is used to perform an impact assessment for Climate Change, Acidification, Ecotoxicity, Respiratory Inorganics, and Respiratory Organics was performed.

Results. The results from direct (process) and indirect (power plants) air emissions confirmed that the major air pollution occurs during Zinc Smelting, that is up to approximately 65–70%. Although an increase in recycling rates resulted in higher levels of air pollution from transportation as well as heavy metals from dross, these two issues were insignificant compared to the huge amount of energy consumed for primary metal production. Based on air pollution from transportation alone, a significant reduction of greenhouse gases and VOCs of 90% each was appreciated when Remelter A was selected.

Conclusion. The results verified that efforts to recycle zinc and consume the material in a more sustainable manner have become highly important. Also, a second LCA investigation that was made to compare zinc cast products that consists of: 100% primary zinc, mixtures of 50–50% and 40–60% primary-to-recycled zinc, and finally 100% recycled zinc; further emphasized the need for using recycled metal, as opposed to using primary metal.

Keywords: Air emissions, direct and indirect; zinc casting; zinc recycling; zinc smelting; zinc, transportation

Introduction

In the metal industry, efficient and cost effective methods are needed to assess the environmental issues that arise from the casting, processing, and recycling stages of various metals. As environmental standards around the world tighten, all types of metal casting companies have come under increased pressure to employ more sustainable manufacturing operations and activities (Xiao et al. 2003; Guo et al. 2002). Although the metal die casting industry is renowned for using recycled metal to produce new goods, further improvements in environmental performances is one of the key challenges affecting the future competitiveness of metal casters. In addition, casting is among the most energy-intensive industries, whereby most of the energy consumed, which can take up to approximately 55% of the total energy costs, is attributed to the melting process (Energetics Inc 1999).

As demands for high quality cast products increases, metal casting industries have been striving to improve the timeliness, productivity, and efficiency of their operations while delivering consistent, high-quality castings at competitive prices. For example, various developments have been made to deliver high performance die cast products at faster rates (Aldham 2002). Other improvements include integrating software technologies with machine operations to enhance casting qualities (Cast Metal Coalition 1998).

However, metal casting and recycling are not the only activities that cause pollution. The production of primary zinc by smelting processes also consumes huge amounts of energy as well as releases high levels of pollution into the environment.

In the drive towards improved environmental performance, the entire system should be analyzed to gain a holistic view of the activities associated with the material cycle. An approach that has been widely applied by many industries for this purpose is LCA.

1 Case Study

The LCA study involves a die casting company in Singapore. The company produces small precision components, with specialized design, tooling and production processes for aluminum and zinc die cast components.

1.1 Product

Metal die casting has been described as the most direct and shortest route from component design to production (Kanicki 1994). Almost any metal that can be melted can also be cast, and the design of the casting can be extremely flexible. This flexibility allows the zinc casting company to produce simple or complex components of infinite variety.

Zinc castings exhibit high strength and hardness and excellent thermal and electrical conductivity. This makes the material ideal for a wide array of castings, ranging from electronic and telecommunication parts to medical components. Zinc cast components are commonly produced by a hot-chamber die casting process. In this process, the molten metal is injected under high pressure into a steel mould to form the cast component. The technology used for the casting process is comparable to those used in the U.S and Europe.

The product that will be used for the LCA study is a 'generic' zinc cast component weighing 100 g. The shot weight of the zinc cast product is 225 g, whereby the runner weight is 125 g. The shot weight consists of a mixture of 50% primary zinc material and 50% recycled zinc material. Typical metal losses due to metal melting and pouring can range between 1–2%. The current reject rates range from 4 to 5%.

It was proposed, in order to reduce both the cost of purchasing primary zinc ingots, and the environmental load from primary zinc production, that the recycled zinc content of the cast product should be increased by 10%. By doing this, the same product will consist of 40–60% primary-to-recycled zinc. However, since recycled zinc tends to contain higher levels of impurities, it was anticipated that the percentages of both casting reject rates and dross from remelting will increase.

1.2 Recycling

For each cast product that is produced, the runner has to be removed from the final product and treated as scrap metal. The accumulated scrap metal will be sent for recycling. The company has initially been sending the scrap metal to Remelter A, which is situated within the company's vicinity, that is, 20 km away. By selecting Remelter A, a total of 10 to 15 tonnes of scrap metal is sent for recycling twice a week by truck. Due to expected lower labor and operating costs, the company is considering a second remelter, Remelter B, which is located in a neighboring country, Malaysia. If Remelter B is chosen, a total of 25 to 30 tonnes of scrap metal will be scheduled to be sent for recycling once a week by truck.

2 Life Cycle Assessment

LCA can be used to assess the environmental performance of a product, process or service, from a 'cradle-to-grave' perspective. LCA is considered to be a holistic approach in measuring the potential environmental impacts of a defined system and has been applied in many ways in both the public and private sectors (Guinee et al. 2001). After defining the objective and scope, the LCA methodology involves several steps (Khan et al. 2002):

- Compiling an inventory of relevant inputs and outputs of a product system
- Evaluating the potential environmental impacts associated with those inputs and outputs
- Interpreting the results of the inventory analysis and the impact assessment phases in relation to the objectives of the study.

2.1 Objective

The objective of the LCA study is for quantifying and comparing the air emissions from casting, remelting and transportation due to:

i) the proposed redesigning of the casting system (increased recycled content of cast product); and
ii) the choice of Remelters (and distance traveled by truck).

2.2 Scope

The scope of the LCA is on the zinc material cycle, including the direct and indirect air emissions associated with the energy consumed for smelting, castings and recycling, as well as air emissions from the shipment of primary zinc and scrap transportation. The 'cradle-to-gate' system boundary, as shown in **Fig. 1**, starts with raw material acquisition (import of primary zinc from U.S.), the casting process, runner and product separation, inspection, scrap transportation and recycling, and ends when the recycled metal is returned to the company by truck.

Within the system boundary, the LCA study will compare the following four scenarios:

- **Scenario 1:** original casting and usual recycling activities (Remelter A)
- **Scenario 2:** re-designed castings (increased content of recycled metal in casting product) and usual recycling activities (Remelter A)
- **Scenario 3:** original casting and selection of new recycling plant (Remelter B)
- **Scenario 4:** re-designed castings (increased content of recycled metal in casting product) and choice of Remelter B.

2.3 Functional unit/reference flow

The life cycle inventory and impact assessment calculations are dependent on the functional unit and reference flow of the LCA. In this case, the functional unit for the system is defined as **one tonne** of the final cast product. The sample calculations for the reference flow for Scenario 1 are shown in **Fig. 2**.

2.4 Life cycle inventory

The two basic sources of air pollution are: stationary emissions (i.e. Smelting, Die Casting and Remelting processes and energy-related emissions), and mobile emissions (i.e. diesel trucks). The Life Cycle Inventory or LCI will focus on:

a) **Stationary air emissions:** Direct or process ('in-situ') air emissions contributing to Acidification, Respiratory Inorganics, and Ecotoxicity; indirect or Power Plant emissions contributing to Climate Change, Acidification, and Respiratory Inorganics
b) **Mobile air emissions:** Direct air emissions contributing to Climate Change, Acidification, Respiratory Inorganics, and Respiratory Organics.

There is no Zinc Smelter in Singapore, the company exports primary zinc metal from US and other European countries. Therefore, the Zinc Smelter's direct ('in-situ') emissions are extracted from:

– UK National Air Quality Information Archive (UK-NAQIA 2002), and
– US Environmental Protection Agency (USEPA 2003).

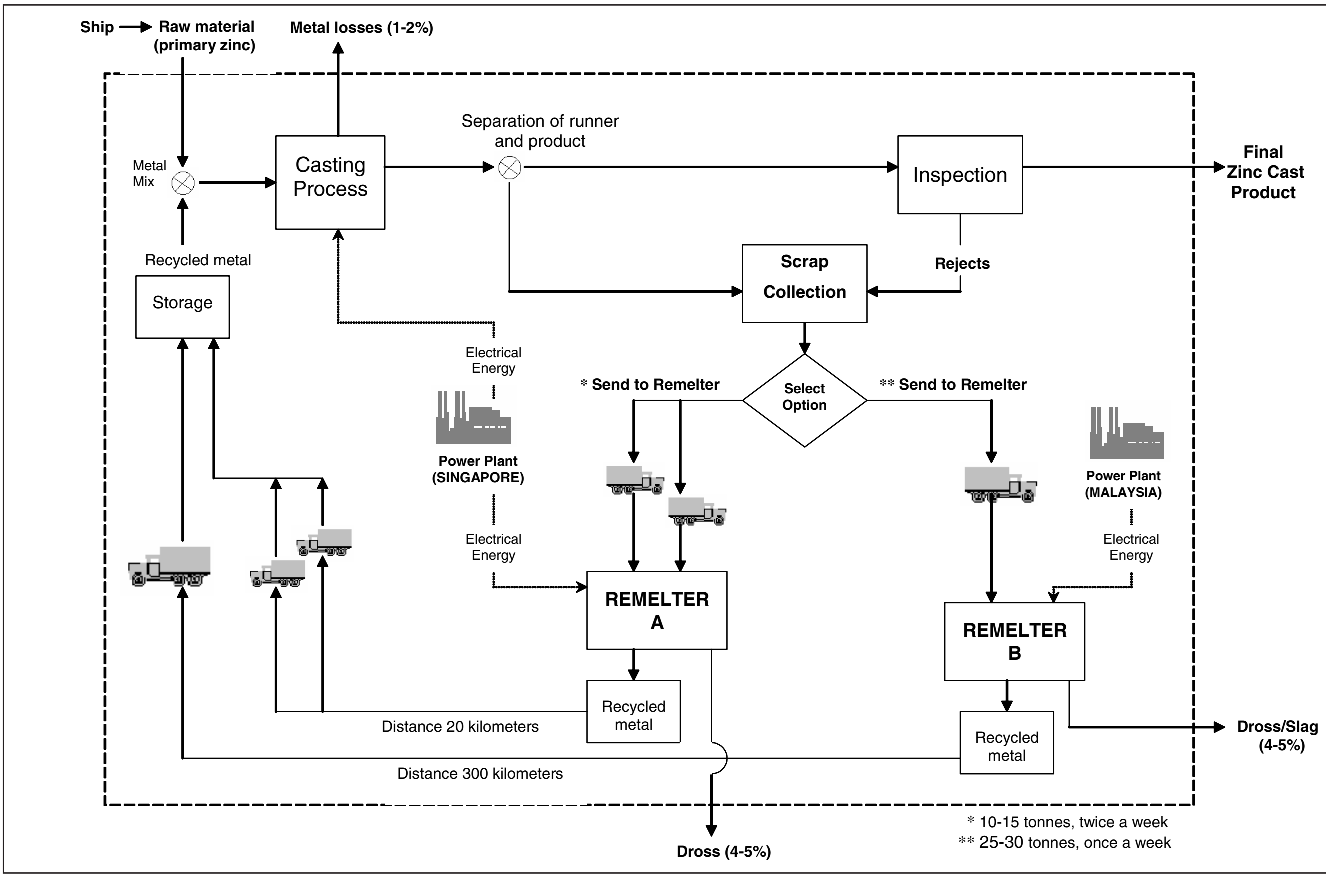

Fig 1: LCA study system boundary

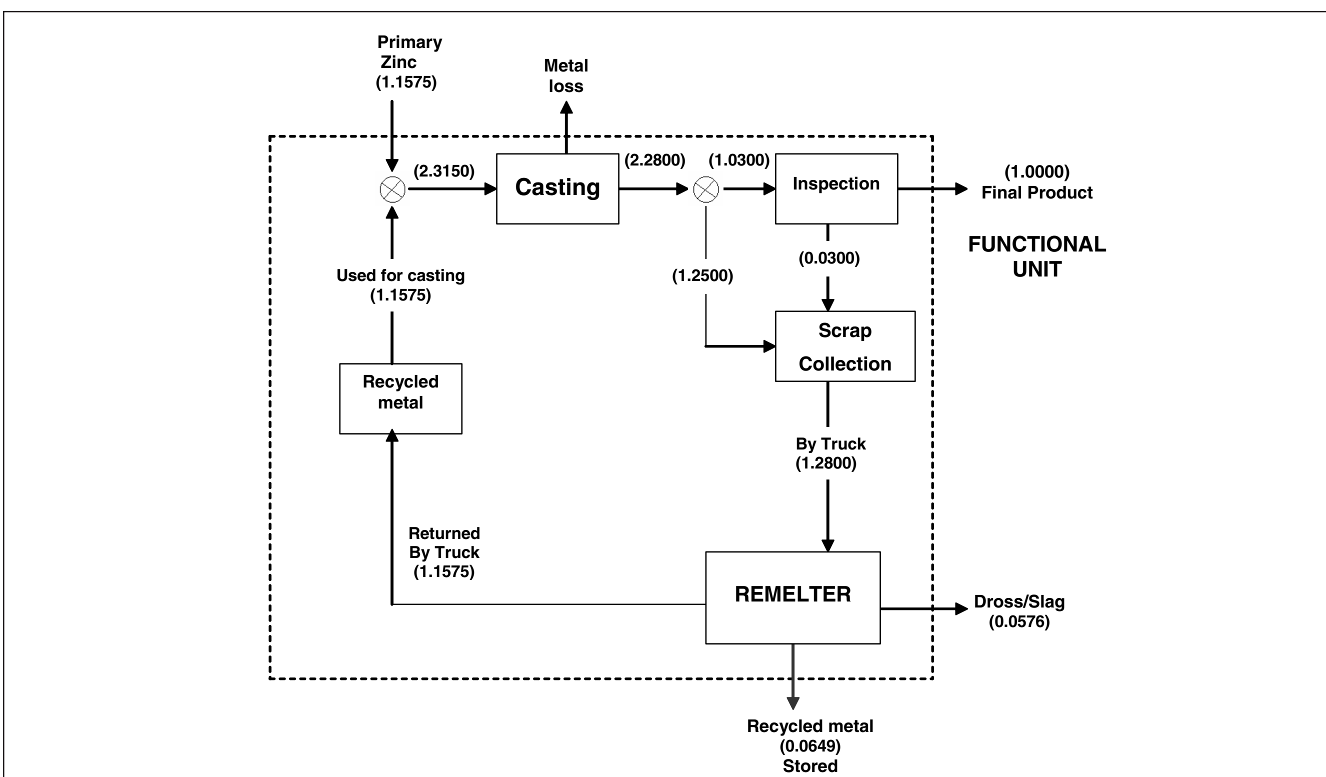

Fig 2: Reference flow for scenario 1

It is estimated that 3400 kWh is required to produce one tonne of primary zinc (Hunter 2001).

The methods used for both casting and recycling of zinc are employed from both U.S. and Europe. Hence, the die casting and remelter direct emissions can be sourced from:

– US Department of Energy (2003), and
– National Pollution Inventory (2003).

The LCI data for the power plant, which provides electricity to both the casting company and Remelter A (both based in Singapore), are extracted from Singapore's electricity generation (Wong 2002). For Remelter B (located in Malaysia), the associated energy data is obtained from Malaysia (Department of Environmental Sciences 2001). The data for diesel truck air emissions are extracted from EURO 2 Emission Standards (2004), which are presently being employed in Singapore. The ship transport emissions are extracted from OECD and Hetch (1997). The estimated distance traveled by ship for the delivery of primary zinc from U.S. to Singapore is 10,000 km.

The LCA study is performed based on the assumption that the process timings and capacities of both remelters are identical. By employing an electric furnace to melt metal with a 50% (typical) efficiency rate, the amount of energy required for casting one tonne of zinc is 208 kWh, and for remelting the same amount of metal is 155 kWh. The energy required for melting zinc was obtained from the Australian Die Casting Association (2003). The theoretical values were calculated based on the requirements to melt zinc alloy containing 4% aluminum metal with a specific heat of 418.7 J/kg/°C and latent heat of fusion (melting) of 112604.65 kJ/tonne.

2.5 Impact assessment and results

The LCA SimaPro software (version 5.0) Eco-indicator '99 method is used to perform an impact assessment for the following environmental impact categories: i) Climate Change, ii) Acidification, iii) Respiratory Inorganics, iv) Respiratory Organics, and v) Ecotoxicity. The normalized results are displayed in Figs. 3 to 11. The Final Weighted Scores are displayed in Fig. 12. The parameters used from the Eco-indicator '99 method are displayed in **Table 1**.

2.5.1 Climate change

Greenhouse gases, mainly carbon dioxide CO_2, are the cause of Climate Change. The result of Climate Change from transportation alone is shown in **Fig. 3**. It can be observed that as much as 90% in CO_2 savings can be appreciated when Remelter A is selected.

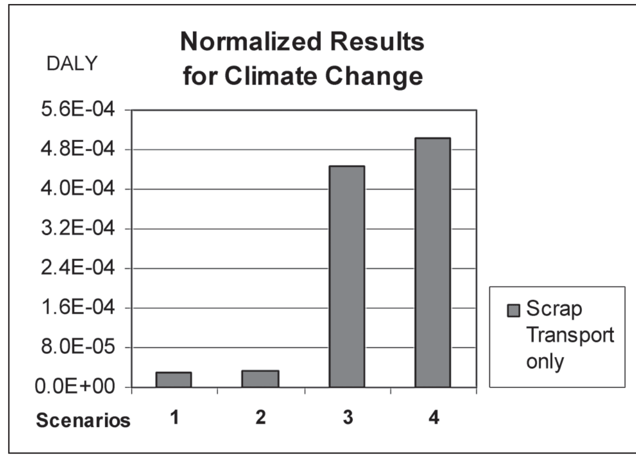

Fig 3: Normalized results for climate change due to transportation

The other main source of greenhouse gases is indirect emissions, that is, those arising from electricity generation. **Fig. 4** shows the results of Climate Change from the power plants that supply electrical energy to the Smelter, Die Caster and Remelters, and transportation. It can be observed that for Scenarios 1 to 4, approximately 75–80% of greenhouse gas emissions are due to Smelting operations. With the increase of recycled metal in the cast product (from 50 to 60%), higher amounts of casting and remelting processes are required. The first reason is due to the higher level of reject rates from casting. The second is the need for more recycled metal to produce the same product. However, compared to Smelting, the energy-related CO_2 emissions from Die Casting and Recycling are very insignificant. The shipment of primary zinc to the company takes up to about 10–12% of the graphs, with very slight variations between the four Scenarios.

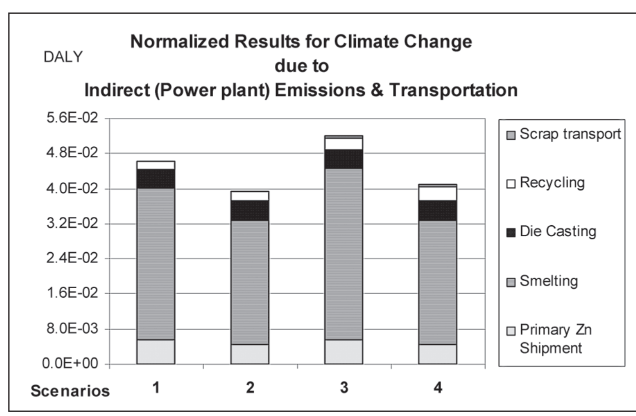

Fig 4: Normalized results for climate change due to indirect emissions

Table 1: Parameters for Eco-Indicator '99 method

Environmental Impact Categories	Damage Category	Normalized Values	Weight
Climate Change (DALY)	Human Health	65.1	300
Respiratory Inorganics (DALY)			
Respiratory Organics (DALY)			
Ecotoxicity (PAF*m2yr)	Ecosystem Quality	1.95 E-4	400
Acidification (PDF*m2yr)			

DALY = Disability adjusted life years
PDF = Potentially Disappeared Fraction of plant species
PAF = Potentially Affected Fraction under toxic stress

2.5.2 Acidification

Acidification is the process whereby air pollution, including oxides of nitrogen (NOx) and oxides of sulphur (SOx), is converted into acidic substances, thus creating acid rain. In **Fig. 5**, the contribution to Acidification is due to the direct emissions from the Smelting, Die Casting and Remelting processes, as well as from transportation. Smelting alone can emit up to 21,500 kg of sulphur dioxide (SO_2) per tonne of zinc, although most of these gases (up to about 97%) are recycled at the desulphurization plants (USEPA 2003). For scenarios 1 and 2, die casting takes up to approximately 25% and 30% of the graphs, respectively. An increase in recycling (from Scenarios 1 and 3 to 2 and 4) results in only 5% higher amounts of NO_x and SO_x gases from the Remelters. Emissions of SO_x and NO_x gases from ship transportation are as significant as those from Smelting operations.

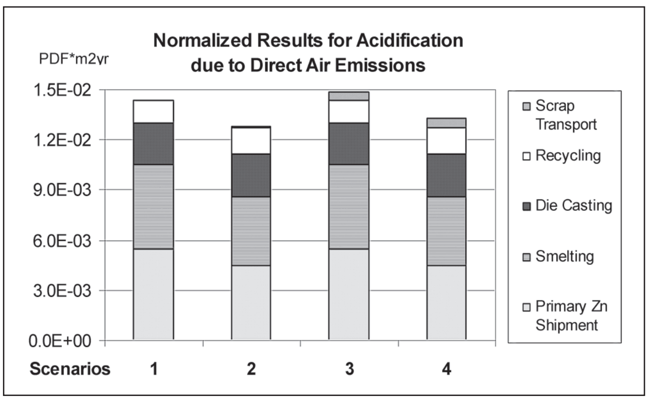

Fig 5: Normalized results for acidification due to direct emissions

Emissions of NO_x and SO_x are also emitted from the power plants supplying energy to the Smelting, Casting and Remelting processes. Due to the large amount of energy consumed for zinc smelting, which is roughly 18 times higher than both Casting and Remelting, the graphs for Scenarios 1 to 4 (**Fig. 6**) follow nearly the same trend as those displayed for Climate Change (see Fig. 4). Ship emissions in this case take up to approximately 20% of the graphs.

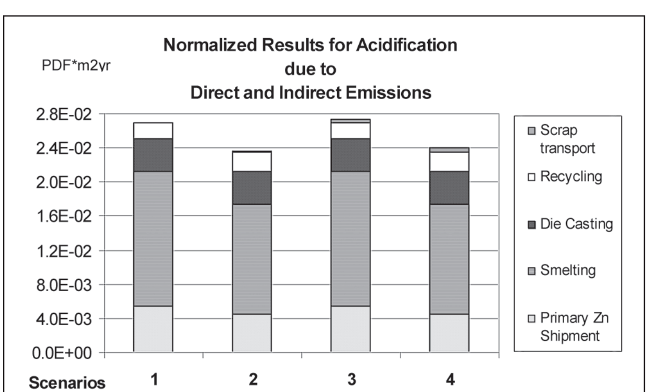

Fig 6: Normalized results for acidification due to indirect emissions

2.5.3 Respiratory inorganics

In **Fig. 7**, the main emissions contributing to this environmental impact category are particulates from all three processes, as well as from transportation. Zinc Smelting alone can emit up to 3.8 kg for each tonne of uncontrolled fugitive particulate emissions (USEPA 2003). For all four Scenarios, the 'in-situ' emissions from the Smelter contribute to up to 80% of the graphs. The next most significant emissions contributing to this impact category is from the shipment of primary zinc.

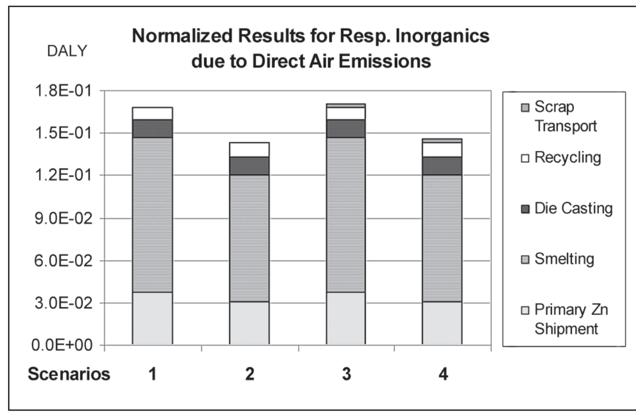

Fig 7: Normalized results for respiratory inorganics due to direct emissions

Fig. 8 shows that approximately 85% of particulates come from the Smelting operations for Scenarios 1 to 4, and a moderate amount from ship transportation. Compared to Smelting, the particulate emissions from Die casting and Recycling due to energy consumption are very insignificant.

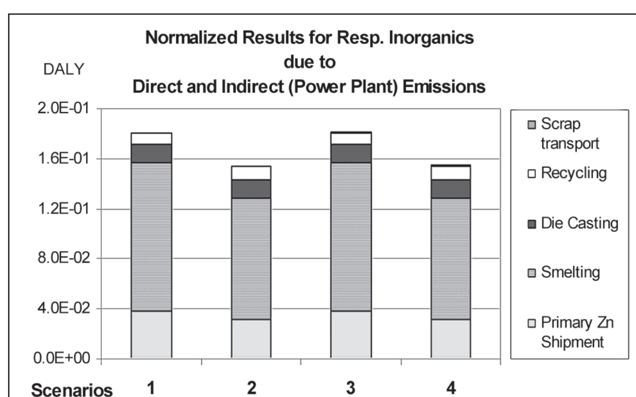

Fig 8: Normalized results for respiratory inorganics due to indirect emission

2.5.4 Respiratory organics

Volatile Organic Compounds or VOCs from transportation alone are displayed in **Figs. 9** (truck) and **10** (ship). The VOCs are from diesel trucks alone, which are the preferred transportation mode for most goods between companies. The emissions of VOCs, combined with NO_x from these mobile

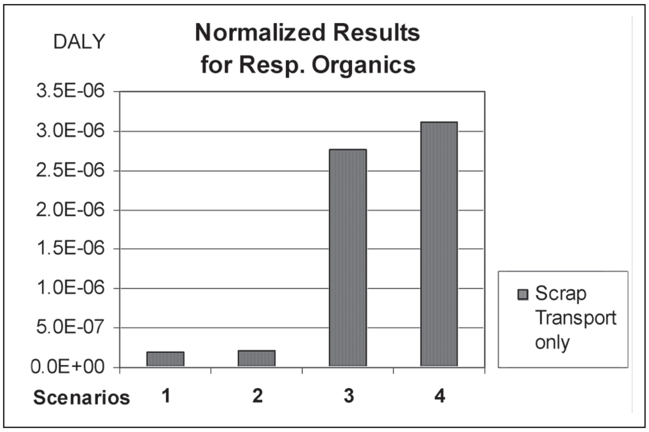

Fig 9: Normalized results for respiratory organics due to truck transportation

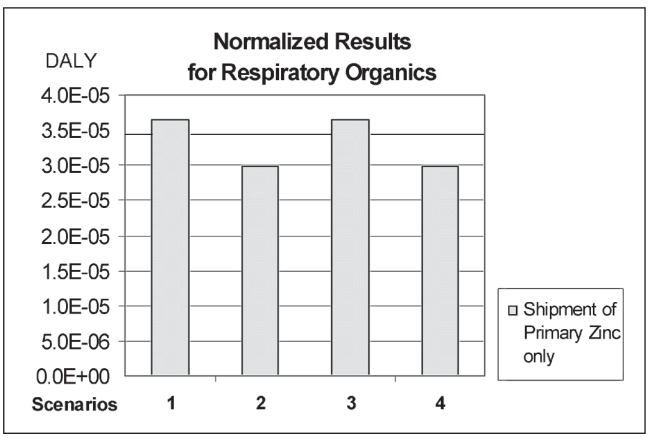

Fig 10: Normalized results for respiratory organics due to ship transportation

sources are a big contributor to ozone formation. When less scrap is transported for recycling, the amount of VOCs produced from trucks is reduced by 18%. And when Remelter A is selected, the amount of VOCs contributing to Respiratory Organics are about 90% less as compared to selecting Remelter B. As for the shipment of primary zinc metal, much less variation (about 20%) is observed between the Scenarios.

2.5.5 Ecotoxicity

The normalized results for Ecotoxicity due to the direct emissions for Smelting, Casting and Remelting are displayed in **Fig. 11**. Remelting of scrap metal produces dross, which contains heavy metals such as cadmium, lead and zinc. Scrap that contains increased recycled metal content is lower in quality and will tend to produce higher contents of dross (and heavy metals) when recycled. However, compared to Smelting, the contribution to Ecotoxicity due to the remelting of scrap is relatively less significant. Fig. 10 shows that an increase of approximately 10% is observed with higher recycling rates (from Scenarios 1 to 2; and 3 to 4). In all cases, Smelting takes up the larger portion of the graphs, that is 60–70%, whereby Casting is approximately 10%. Transportation does not contribute to the results of ecotoxicity.

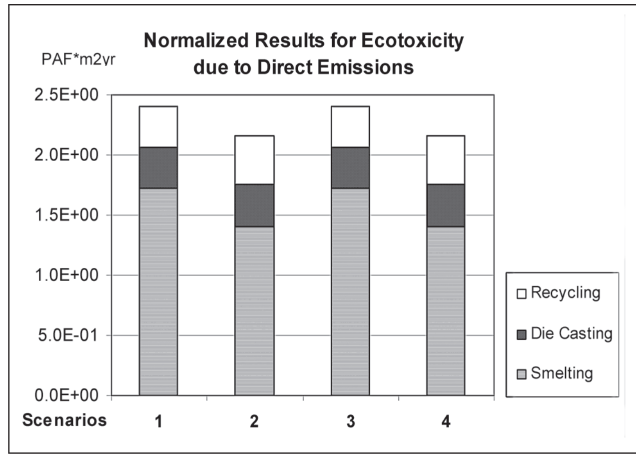

Fig 11: Normalized results for ecotoxicity due to indirect emission

2.6 Final weighted scores

In the Final Weighted Scores (**Fig. 12**), Smelting alone contributes up to 65% (Scenarios 1 and 3) and over 70% (Scenarios 2 and 4) of the overall environmental loads. Although increased recycling results in higher amounts of emissions from recycling activities and transportation, these two add up to a very insignificant quantity compared to the huge amount of emissions (direct and indirect) from Smelting. Also, the direct emissions from the Smelting process emits SO_2 and particulate gases that are nearly two to five times higher than casting and recycling combined.

By reducing the use of primary zinc metal by 10%, a reduction of 11% in the total environmental load was observed. Also in Fig. 12, the environmental impact of transportation is hardly noticeable. However, by performing an impact assessment on truck transportation *alone*, the amount of CO_2 and VOCs that can be reduced (Figures 3 and 9) are highly significant (90%). Therefore, based on this, the company should select Remelter A.

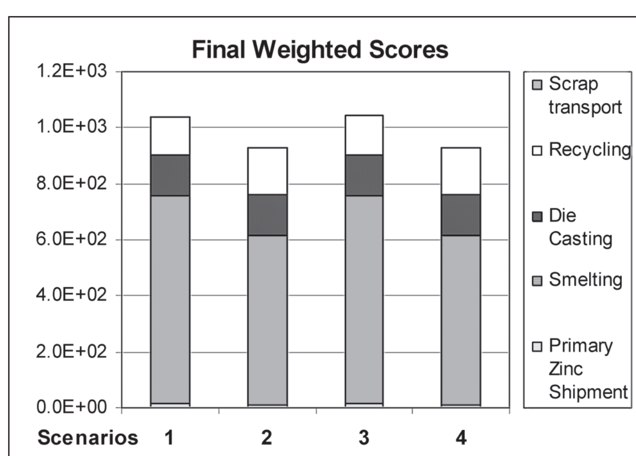

Fig 12: Final weighted scores

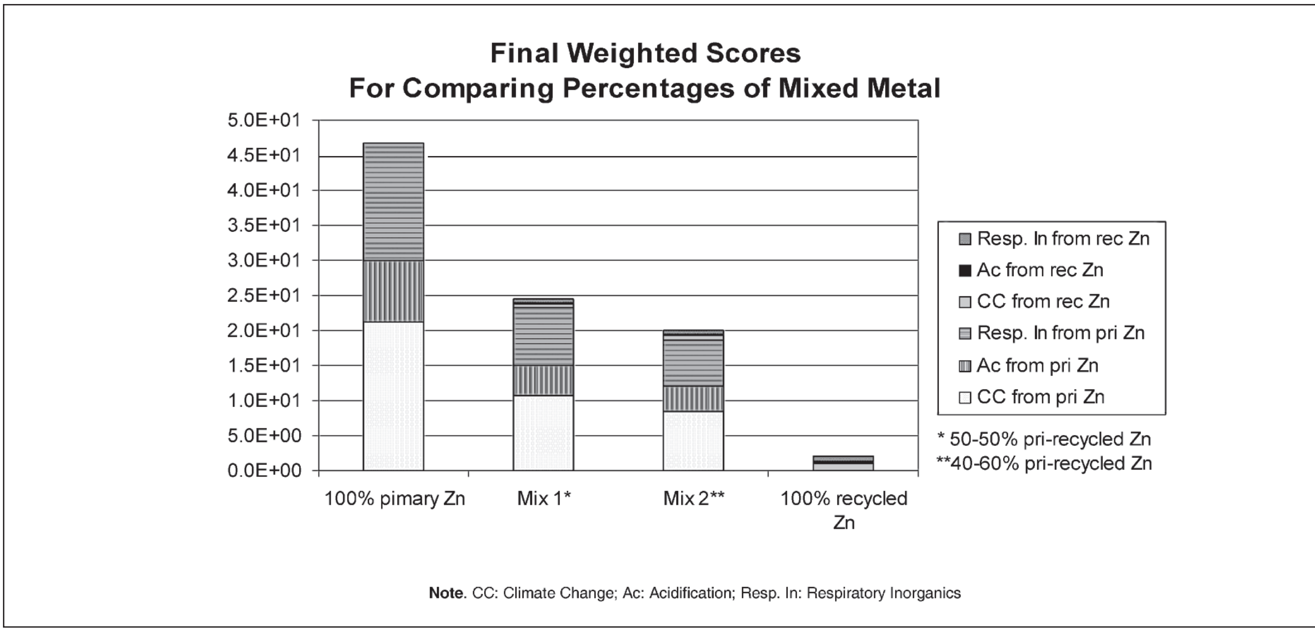

Fig 13: Final weighted scores comparing various metal mixes

3 Further Investigation: The need for increased recycling

Zinc is an example of an 'extremely scarce resource' (Legart 1996). Therefore, efforts to recycle zinc and consume the material in a more sustainable manner have become very important. The global production of zinc in 1999 has been estimated at 8 Mt (Hassall et al. 2000). It was anticipated, given the contemporary trend in consumption, that most metals (including zinc) will be exhausted before the year 2100 (Legart 1996).

In terms of energy consumption, secondary or recycled zinc consumes less than 10% of the energy required to produce primary zinc. By using more recycled metal, huge amount of air pollution generated by power plants can be eliminated. **Fig. 13** displays the Final Weighted Scores (indirect emissions) for the primary-to-recycled metal mixes of: 100% primary zinc, 50–50% primary-to-recycled zinc, 40–60% primary-to-recycled zinc, and finally 100% recycled zinc.

From the first (100% primary metal) to the second graph and third graph (metal mixes), up to about 50% reduction in power plant emissions can be reduced. And when 100% recycled zinc is used, the overall environmental load drops by 90%. However, due to adverse affects on material characteristics and product quality, it is impossible to use 100% recycled zinc for casting. But efforts to increase the content of recycled zinc, from its present value in castings, should continue.

The zinc industry's interest in recycling will continue to grow. This interest should not exclude Singapore companies, where environmental management has been given even greater impetus by the rapid globalization of the world economy. Apart from that, the zinc industry's interest in recycling may be influenced by emerging trends in public policy and law, marketing demands and consumer needs. Some of these trends were discussed by Parker (2002) as indirect and direct forces that drive the recycling of zinc 'beyond economic incentives' and 'environmental implications' for metal products. Among the key issues that were highlighted by the author are:

– Corporate determination to pursue sustainable practices and product stewardship,
– public perceptions and pressure,
– customer and investor demand,
– workforce recruitment,
– protection and expansion of markets.

4 Further Recommendations

From a global perspective, the smelting of zinc should be the main focus for environmental management and improvement. This includes the reduction of 'in-situ' emissions from zinc smelting, such as SO_2, particulates and heavy metals, by implementing pollution monitoring or control technologies. Another focus area lies in reducing the energy consumption of the processes involved in the production of primary zinc.

Since the case study is based in Singapore, the rest of the recommendations will focus on energy-related emissions from Casting and Recycling. Future developments should pay attention to improving the energy efficiencies of die casting and remelting methods, as well as the production of 'cleaner' energy. As outlined in the Singapore Green Plan 2012 (SGP 2001), Singapore's target is for natural gas to be used in generating 60% of the electrical energy by the year 2012; the remaining 40% will continue to be supplied by fuel-fired power plants. This will reduce the country's CO_2 emissions from electrical energy generation by 8.8% for every 1 kWh produced (Wong 2002). Since the electricity demand in Singapore is approximately 29,000 GWh annually, this can lead to a huge amount of CO_2 savings. This adds to the reason for the company to send scrap metal to Remelter A.

5 Conclusion

This paper demonstrated how LCA is used to help make and verify decisions that can lead to minimizing the overall potential environmental loads associated with the material cycle of zinc metal. The LCA case study (from gate-to-gate) focused on a die casting company in Singapore. Based on a 'generic' zinc casting product, the objective of the LCA was to compare the air emissions from casting, recycling and transportation due to: i) the possibility of redesigning the casting system to achieve 20% reduced runner weight; and ii) the choice of selecting between two Remelters to send zinc scrap for recycling.

The impact assessment results confirmed that Smelting alone contributes up to approximately 70–80% of the overall environmental loads for the entire material cycle. The increase in air pollution resulting from higher recycling rates and transportation proved to be very insignificant compared to the huge amount of pollution due to primary metal production.

Further LCA investigations compared the total environmental loads due to using various metal mixes to produce cast products, including: 100% primary zinc, 50–50% and 40–60% primary-to-recycled zinc, and 100% recycled metal. It was projected that in order to reduce the huge amount of pollution that occur for primary zinc production, as well as prevent the rapid depletion of zinc resources, metal casters have to consume zinc in a more sustainable manner.

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LCA Case Study for Lead and Zinc Production by an Imperial Smelting Process in China

A Brief Presentation

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An LCA case study was conducted for the production of lead and zinc by an Imperial Smelting Process (abbreviated hereafter as ISP) in Shaoguan Smelter, China. The detailed inventory analysis was performed by allocating the Input/Output among the main products. The environmental impacts were assessed by using the following five Eco-indicators: Gross Energy Requirement (GER), Global Warming Potential (GWP), Acidification Potential (AP), Heavy Metal Toxicity (HMT) and Solid Waste Burden (SWB). This study is useful to address the environmental situation of the ISP practiced in this smelter, and provides a scientific basis for further improvement.